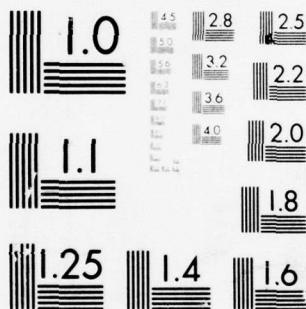END
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Technical Note

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title: IMPROVED CHEMICALS FOR FIBERGLASS-REINFORCED
PLASTIC SOIL SURFACINGS — FIELD EVALUATION

author: M. C. Hironaka

date: September 1978

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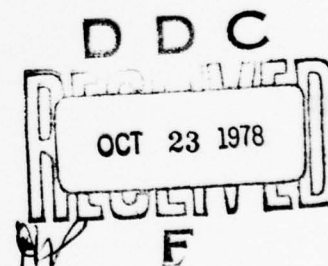**sponsor:** Naval Facilities Engineering Command

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CIVIL ENGINEERING LABORATORY

NAVAL CONSTRUCTION BATTALION CENTER
Port Hueneme, California 93043

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A new chemical formulation was recently developed for constructing fiberglass-reinforced plastic surfacings for soils; it consists of a polyester resin, cumene hydroperoxide catalyst, and Vanadium Ten-Cem/N,N-dimethyl-p-toluidine solution promoter. This report documents the field testing of this new formulation with present Marine Corps spraying equipment. It was found that the new formulation is superior to the formulation used in the past because it: (1) provides surfacings with higher strength properties, (continued)

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20. Continued

(2) is easier to mix due to the constant ratio of 1.0 to 0.25 between catalyst and promoter for any temperature, (3) is more economical to use in temperatures below 110°F, and (4) increases pumping/spraying reliability by eliminating the catalyst material that precipitates out of the emulsion during storage and eventually causes fouling of check valves and other pumping mechanisms. Furthermore, it was found that the resin used in this new formulation has a shelf life of more than 5 years based on accelerated aging tests as compared to the previously used resin, which had a guaranteed shelf life of only 4 months at the same temperatures.

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A new chemical formulation was recently developed for constructing fiberglass-reinforced plastic surfacings for soils; it consists of a polyester resin, cumene hydroperoxide catalyst, and Vanadium Ten-Cem/N,N-dimethyl-p-toluidine solution promoter. This report documents the field testing of this new formulation with present Marine Corps spraying equipment. It was found that the new formulation is superior to the formulation used in the past because it: (1) provides surfacings with higher strength properties, (2) is easier to mix due to the constant ratio of 1.0 to 0.25 between catalyst and promoter for any temperature, (3) is more economical to use in temperatures below 110°F, and (4) increases pumping/spraying reliability by eliminating the catalyst material that precipitates out of the emulsion during storage and eventually causes fouling of check valves and other pumping mechanisms. Furthermore, it was found that the resin used in this new formulation has a shelf life of more than 5 years based on accelerated aging tests as compared to the previously used resin, which had a guaranteed shelf life of only 4 months at the same temperatures.

CONTENTS

CONVERSION TABLE

To Convert From	To	Multiply By
inch	meter	0.0254
foot	meter	0.3048
square foot	meter^2	0.0929
cubic foot	meter^3	0.0283
psi	Pa	6894.0
pound	kg	0.4535
gallon	meter^3	0.0038
centipoise	Pa·s	0.0010
°F	°C	$t_c = (t_f - 32)/1.8$

INTRODUCTION

Objective

The objective of this investigation was to evaluate under field conditions the newly developed chemical components for fiberglass-reinforced-plastic (FRP) expedient flexible membrane surfacings for soils. These surfacings are intended for use by Marine Corps forces in amphibious landing operations for such applications as light-duty trafficable surfaces and erosion/dust control from jet blast, wind, and water.

Background

In previous research efforts, the Civil Engineering Laboratory (CEL) in conjunction with the Marine Corps Development and Education Command developed systems to construct FRP flexible membrane surfacings for soils. These systems were called the Manual Spray Unit (MSU) and Low Rate Unit (LRU) (Ref 1). These systems are capable of constructing surfacings consisting of two layers of fiberglass matting at the rate of 1,600 and 2,000 ft^2/hr, respectively. A system known as the High Rate Unit, which is capable of constructing surfacings with double layers of fiberglass at the rate of 10,000 ft^2/hr, was developed for the Air Force (Ref 2). All of the above systems were developed under contracts with the Boeing Company.

Various field demonstration projects validated the utility of FRP as a flexible membrane surfacing for light-duty trafficable surfaces as well as in other applications, such as reservoir and ditch linings. Controlled simulated traffic tests with a standard loaded dual truck wheel assembly showed that FRP is very durable (Ref 3). FRP test sections overlaid on competent lean and heavy clay soils showed very little effects of the loaded wheel even after 10,000 passes.

Although the utility and durability of FRP as a flexible membrane surfacing for soils has been proven, deficiencies existed with the chemical components used in formulating these surfacings as documented in References 1 and 3 and as related by operational personnel from field experiences. The deficiencies that existed were:

Resin*   - Short shelf life (guaranteed for only 4 months). This shelf life is unacceptable, if it is to be considered as a stockpiling item for war reserve purposes.

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*A thermosetting polyester resin containing 35% styrene monomer.

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Catalyst*   - Short shelf life (has not been completely established, but it can be measured in months, not years). The precipitated benzoyl peroxide crystals have often been the cause of pumping/metering system malfunctions and operational delays.

Promoter**   - Has a long shelf life, but is highly toxic.

Because of the above deficiencies in the chemical components, a research and development program was initiated to develop new components. The objective of the program was to develop chemical components, each of which would have a minimum shelf life of 5 years and would be compatible with the basic, previously mentioned Low Rate Unit. There were also the requirements that the resulting FRP would have engineering properties equivalent to or better than those constructed with the old components and that all other deficiencies in the system would be minimized where practical or otherwise not aggravated further. The developmental effort for the new components was successfully completed and documented under contract with the Dow Chemical Company (Ref 4). This report documents the results of the field testing of the new chemical components with one of the modified Marine Corps Low Rate Units.

CHEMICAL COMPONENTS

Description and Properties

The new chemical components consist of a polyester resin, a catalyst (cumene hydroperoxide) and a two-part, premixed, liquid promoter (Vanadium Ten-Cem***/N,N-dimethyl-p-toluidine) (Ref 4). The composition and properties of each of these components are shown in Table 1. All of the components occur in a liquid state at the temperatures expected during spraying operations (normally >32°F); thus, the possibility of precipitants occurring as with the previously used benzoyl peroxide catalyst does not exist.

The two-part promoter is premixed prior to spraying operations. The ratio of the components used in the promoter solution is 1.2 parts of Vanadium Ten-Cem to 1.0 parts of N,N-dimethyl-p-toluidine by volume. These two components can be mixed far in advance of the time they will be used. Reactivity tests using promoter solutions stored over various periods of time showed that the promoter is stable and essentially unchanged even after 5 months of storage (Ref 4). Longer term tests were not conducted; therefore, the maximum time (if any) that the promoter solution can be stored has not yet been defined.

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*An emulsion containing 40% benzoyl peroxide in a dibutyl phthalate diluent.

**100% N,N-Dimethylaniline.

***Since April 1978, Mooney Chemicals, Inc. has discontinued producing Vanadium Ten-Cem. A search for a substitute chemical is underway.

Procurement

Procurement information for the new chemicals is shown in Table 2. The cost per pound for each chemical is for small quantity orders. These prices can be expected to be less for quantities required in a Marine Corps amphibious landing operation. The polyester resin and the Vanadium Ten-Cem can be procured only from the indicated manufacturers; other sources are available for procuring the cumene hydroperoxide and the N,N-dimethyl-p-toluidine than those indicated.

FIELD TESTING

The field testing of the new chemical components was conducted with the newly configured Marine Corps Low Rate Unit at the Marine Corps Development and Education Command facility in Quantico, Virginia, in June 1977. An area approximately 30 by 65 feet adjacent to the north-west end of the Butler Building at the Engineer Test Site was prepared for surfacing with FRP.

Chemical Component Preparation

A portion of the resin was artificially aged, and the promoter solution was prepared at Port Hueneme prior to shipping them to the spray test site at Quantico. The catalyst was shipped as received from the vendor.

Six 55-gallon drums of resin were placed in a heating chamber at the Pacific Missile Test Center, California, to artificially age the resin. The chamber temperature and time duration for the two aging periods were 107°F for 383 hours followed by 115°F for 1,257 hours. Two aging periods occurred because of a calibration problem of the sensors at the beginning of the aging process.

It was initially desired to age the resin to an equivalent age of 5 years. However, due to a change in equipment scheduling,* it was necessary to terminate the aging process and perform the field tests earlier than planned. As a result, an equivalent age of only 30 months was achieved. The change in resin viscosity with respect to time of aging at 107°F and 115°F is shown in Figure 1.

Another six 55-gallon drums of resin were stored in a warehouse at the Naval Construction Battalion Center, Port Hueneme, California, and permitted to be aged naturally at ambient temperatures. No special effort was made to monitor the ambient temperature in the warehouse building where the resin was stored. The viscosity of the resin aged at ambient Port Hueneme temperature for 6 months was measured to be 199 centipoises (cps) by the Brookfield Viscometer method. This viscosity is 9 cps higher than the viscosity as manufactured.

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*The spraying equipment was required on a higher priority project.

The promoter, consisting of a 1.2/1.0 by volume Vanadium Ten-Cem/ N,N-Dimethyl-p-toluidine solution, was prepared and shipped to Quantico about a month prior to the field spraying tests. The actual amount of each component used in the solution was obtained by using the relationship

$$W_{Van} = 1.34 \ W_{DMT} \tag{1}$$

where W_{Van} =   Vanadium Ten-Cem, weight

         W_{DMT} =   N,N-dimethyl-p-toluidine, weight

The number 1.34 is the factor obtained from the conversion of the 1.2/1.0 ratio by volume to the weight relationship above, which includes specific gravity values for each of the components. The actual amounts used in the solution were 19.3 pounds of Vanadium Ten-Cem and 14.4 pounds of N,N-dimethyl-p-toluidine. The preparation of the solution consisted simply of pouring the components into a 5-gallon container, capping it, and shaking the contents manually for about a minute. The container was then packed for shipping.

Equipment Preparation

In previous efforts, one of the Low Rate spraying units was reconfigured into a SIXCON module* as shown in Figure 2. This unit was placed on a trailer along with the reservoirs for the chemical components as shown in Figure 3. Shown in this figure are the two plastic-lined wooden totes for the resin. The catalyst and promoter reservoirs and a 55-gallon drum of solvent are located on top of the SIXCON pumping unit.

The catalyst and promoter pump systems were calibrated with the components set up as described above. The catalyst and promoter lines were disconnected at the points where each chemical entered the main resin conduits, and an adjustable pressure relief valve was installed on the end of each line. The catalyst system was calibrated first, followed by the promoter system. The calibration of each system was accomplished according to the following procedures:

1. The reservoir was filled with water, and a spring was installed in each pump's discharge cartridge to provide back pressure.

2. The engine speed was set at 2,400 rpm (at which the pump speed is 400 rpm).

3. The pump capacity control valve was set on 10, 20, 40, 60, 80, or 100. The water being pumped through the system was collected in a container located on a weighing scale. The pressure relief valve was

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*A SIXCON module is 1/6 of an 8x8x20-foot container.

set at a reading of 100 psi for control valve settings above 20. For settings at 20 and below, the pressure relief valve was set for the maximum obtainable, which was always less than 100 psi.

4. After the flow stabilized, an initial weight reading was taken while simultaneously activating a stop watch. Several weight and time readings were taken over a period of about 5 to 7 minutes. Then the pump capacity control valve setting was changed to a new value.

5. The resulting water weight and time data were then reduced in terms of flow rates and plotted against pump settings as shown in Figure 4.

6. The pump capacity control valve settings for the proper amount of catalyst and promoter for various temperatures to obtain a gel time of 10 minutes were established as follows:

a. The relationship of gel time as a function of the amount of cumene hydroperoxide required at various temperatures as shown in Figure 5 was used to develop Figure 6 (which presents the relationship in a better form for field use).

b. The resin pump output of 66.3 lb/min at a pump speed of 400 rpm was determined from Figure 7.

c. The volume of cumene hydroperoxide required to cause gelling of the above amount of resin in 10 minutes at each selected temperature was then calculated using data as determined from Figure 6. With the computed volume, the pump capacity control valve setting for that particular temperature was obtained from the pump calibration plot of Figure 4. The settings for the promoter pump were obtained by using the same procedure, except that a fixed ratio of promoter equalling 25% of the catalyst amount (in parts per hundred parts of resin) as determined from Figure 6 was used.

d. The pump capacity control valve settings for both the catalyst and promoter pumps were then plotted at each respective temperature as shown in Figure 8. During the field tests, the settings for the pumps were obtained from this figure.

After the calibration procedures were completed, all reservoirs and lines containing water were drained and flushed with solvent. The pressure relief valves were disconnected from the lines, and the lines were reconnected to the hookup required for spraying operations. The catalyst and promoter were placed in their respective reservoirs, the resin hoses were hooked up to the resin supply, and the cleaning solvent was loaded in preparation for spraying.

Construction Procedure

The following procedure was used in constructing the 30x65-foot test pad:

1. A motor grader was used to level the pad and cut the ditch along the perimeter of the pad.

2. Rocks and objects that could puncture the FRP during service were removed by hand raking as shown in Figure 9.

3. A layer of fiberglass matting was placed with a 6-inch overlap between adjacent strips.

4. The resin was sprayed on and the fiberglass rolled as shown in Figure 10.

5. A second layer of fiberglass was placed over the first layer after the whole 30x65-foot first layer area was completely sprayed.

6. The second layer was then sprayed with the resin and rolled.

Generally speaking, the resin in the first layer had cured before the second fiberglass layer was placed. On the northern one-third of the pad, a third layer with fiberglass strips perpendicular to the first two layers was also placed. The bottom layer was sprayed with "aged" resin, while the upper layers were sprayed with "ambient-aged" resin.

Just prior to spraying the resin on the first fiberglass layer, the temperature at the surface of the fiberglass was measured to be 82°F. With this temperature, the initial pump control valve settings were 34 for the catalyst and 7 for the promoter as determined from Figure 8. Upon initiation of spraying, it was determined that the gel time with these settings was 3 minutes for resin contained in a bucket. These settings were reduced in increments until a setting of 20 for catalyst and 3 for promoter produced a gel time of the resin in the matting of approximately 6 minutes.

TEST RESULTS

In general, the results of the spraying tests of the new chemicals under field conditions showed that the chemicals can be satisfactorily applied to produce acceptable FRP surfacings. Figure 11 is an overall view of the completed test pad. The appearance of the completed FRP was not as good as some previously constructed surfacings formulated with the old chemicals. However, the appearance of the FRP surface was most likely due to inexperience of the personnel constructing the surfacing.*

The appearance of the surfacing was degraded by the occurrence of resin-starved areas (Figure 12), areas with excess resin (Figure 13), and areas with wrinkled fiberglass matting (Figure 14). Areas with excess resin are to be expected since it will accumulate in depressed areas. These areas should not affect the utility of the surfacing. The resin-starved areas and the areas with wrinkled fiberglass matting, however, are indicative of an inexperienced crew. It is undesirable to

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*This was the first project using the new chemicals and only the second surfacing constructed by the crew.

have these areas occur in a finished surfacing, because water could seep through the open pores in the matting in the resin-starved areas or through cracks which would occur in the FRP upon trafficking over the wrinkles. The water, of course, weakens the subgrade and is the underlying cause of FRP surfacing failure.

During the construction of the test pad, test samples consisting of two layers of fiberglass matting were made with the artificially aged and naturally aged resins using the same spraying equipment and rollers. However, a somewhat different procedure was followed: (a) approximately a 2-foot-square fiberglass cloth was placed on a similarly prepared ground surface adjacent to the test pad, (b) resin was sprayed on this layer, (c) a second fiberglass cloth of the same size was immediately placed over the first layer, (d) resin was sprayed on this second layer, and (e) the rollers were applied over the fiberglass layers.

Within approximately 90 days of fabrication of the samples, test specimens for shear, tensile, and flexure strengths were cut from each sample and subjected to standard ASTM tests (D732-46, D638-76, D790-71, respectively). The results from these tests are shown in Table 3. Also shown in this table for comparison purposes are the results from strength tests of FRP specimens made with the old chemical formulation. For both the old and new chemical formulations, the soil type on which the specimens were made and the age of the resin used are documented.

DISCUSSION

The new chemical components used in formulating FRP surfacings have the following advantages over the old chemical components:

1. Long shelf life

2. Better FRP properties

3. Fixed catalyst/promoter ratio

4. Lower cost

5. Improved pumpability

Shelf Life

In the development of the new chemical components, the objective for the shelf life length was 5 years. As shown in Table 1, this objective has been achieved for the resin. The promoter components, which consist of N,N-dimethyl-p-toluidine and Vanadium Ten-Cem, most likely meet the shelf life objective also. (The N,N-dimethyl-p-toluidine has an unlimited shelf life, while the Vanadium Ten-Cem shelf life is not yet defined but may be as long as 5 years or better.) The manufacturers of the cumene hydroperoxide catalyst do not recommend long-term storage (Ref 4). The catalyst and promoter components were not evaluated for shelf life in this investigation; however, a partial evaluation was performed on the resin using the elevated temperature accelerated aging technique.

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The resin was aged to an equivalent time and temperature duration of 2-1/2 years at 75°F. At this age, the viscosity at 77°F increased to 294 cps from a value of 190 cps as manufactured, but it was still well within the 1,600-cps maximum viscosity capability of the resin pump. The projected viscosity for an equivalent 5-year duration would be approximately 340 cps, which is also well within the pump capability. Thus, the new resin has a shelf life of more than 5 years based on accelerated aging tests as compared to the old resin which has a guaranteed shelf life of only 4 months at the same temperatures.

FRP Properties

Based on laboratory tests and observations, the use of the new formulation results in an FRP surfacing that has better properties than the old formulation. Laboratory FRP specimens fabricated with the new formulation had an average tensile strength of 20,500 psi and an average flexural strength of 40,800 psi (Ref 4). By comparison, laboratory specimens fabricated in a similar manner but with the old formulation had average strengths of 18,215 psi in tension and 36,136 psi in flexure (Ref 2). Thus, laboratory specimen strengths were approximately 13% higher for FRP specimens made with the new chemicals as compared with FRP specimens made with the old chemicals.

Strength data for field-constructed FRP specimens do not clearly exhibit higher values with the new formulation as can be seen from the data in Table 3. The FRP strengths for these specimens seem to vary considerably. One factor causing this variation is the soil type and properties on which the FRP is constructed. The data, however, suggest that the FRP properties using the new formulation may be somewhat better than those with the old formulation. FRP strengths may be higher with the new formulation as there seems to be less "crazing" of the excess resin accumulated in low lying areas.

Fixed Ratio

The third advantage of the new chemical formulation over the old formulation is the capability to use at any temperature a fixed ratio of 1 to 0.25 (by volume) for the amounts of catalyst and promoter. This capability simplifies calibration of the pumps and facilitates hand-mixing of small resin batches for patch-up work and testing (such as for gel time). Once the amount of cumene hydroperoxide catalyst is determined from Figure 6 for a specified temperature and gel time, the amount of promoter required is simply 25% of the catalyst volume as determined previously. In the old formulation, the amounts of catalyst and promoter varied with temperature but at different rates; thus, it was necessary to determine independently the catalyst and promoter amounts for any specific temperature. This procedure requires more time and increases the possibility of using an incorrect formulation.

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Cost

The fourth advantage of the new formulation over the old formulation is cost. A comparison of the cost of each of these formulations is shown in Figure 15 in which costs per square foot per FRP layer are plotted against temperature. Note that there are two plots for the new chemicals; they reflect the cost of the N,N-dimethyl-p-toluidine when purchased in small gallon-size quantities (at $6.41/lb) and when purchased in 55-gallon lots (at $3.40/lb).

In Figure 15, it can be seen that the cost of both the new and old formulations varies with temperature. This variation occurs because as the temperature decreases, the amount of catalyst and promoter required to achieve a gel time of 10 minutes increases. Thus, as the temperature decreases, the catalyst and promoter cost increases. However, the rates of cost increase with decrease in temperature are not the same for the new and old formulations. Because of this difference in rate increase, it is more economical to use the new formulation for temperatures below $110^{\circ}F$. Above this temperature, the cost variation between the two formulations will be small.

To illustrate the cost advantage of the new formulation over the old formulation, an example surfacing area of 1,000,000 sq ft and an ambient temperature of $80^{\circ}F$ will be assumed. The combined cost of catalyst and promoter for these conditions for the new formulation is $14,500, while the corresponding cost for the old formulation is $32,500 ($18,000 higher). These costs do not include the logistics cost of shipping and handling the additional quantities required of the old formulation. The cost savings become even more significant if an amphibious landing scenario of 8×10^{6} sq ft total combined surfacing for logistics support areas, access roadways to ammo supply points, and main supply roadways are considered.

Pumpability

The fifth major advantage of the new chemical formulation over the old formulation is the improved pumpability of the catalyst components. The improvement results from a lower viscosity fluid being pumped and the absence of precipitants to foul check valves and pumping mechanism. In the old formulation, the catalyst consisted of a 40% benzoyl peroxide emulsion that had a viscosity of 2,500 cps at $77^{\circ}F$. The manual for the catalyst pump indicates that output volume can be controlled reliably for liquids with viscosities up to 40 cps. Since this viscosity is far exceeded by the benzoyl peroxide emulsion, the pump housing was redesigned to accommodate the higher viscosity. However, the higher viscosities of the emulsion, especially at lower temperatures, may have been the cause of pump malfunctions. The benzoyl peroxide crystals that precipitate out of the emulsion during storage have been the cause of pump malfunctions on practically every spraying operation.

The new cumene hydroperoxide catalyst does not have the negative features of high viscosity and crystal occurrence. It has a viscosity of 8.5 cps at $77^{\circ}F$, which is well within the 40-cps capability of the

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catalyst pump, and it occurs normally as a liquid. Thus, with the low viscosity and absence of crystals, the potential for down time of spraying operations due to catalyst pump malfunctions has been practically eliminated. The field test of the new chemicals reported herein was performed without a single malfunction in the catalyst pumping system as is normally experienced with the promoter system.

CONCLUSIONS

1. The newly developed 5-year shelf life chemical formulation, which consists of a polyester resin, a cumene hydroperoxide catalyst, and a Vanadium Ten-Cem/N,N-dimethyl-p-toluidine promoter, provides a better FRP surfacing than the old chemical formulation (polyester resin, benzoyl peroxide catalyst, and N,N-dimethylaniline promoter).

2. The new chemical formulation can be used without modifying the present MARCORPS spraying equipment.

3. There are no apparent significant differences in sprayability or FRP properties when artificially aged or naturally aged resins are used.

4. The new chemical formulation when compared with the old formulation:

    a. is more reactive.

    b. provides FRP surfacings with better strength properties; for example, average strengths in tension and flexure of 20,500 psi and 40,800 psi versus 18,215 psi and 36,136 psi were measured from tests on laboratory specimens.

    c. makes it easier to calibrate the pumps and to mix small batches of resin for patching purposes because of the fixed ratio of catalyst to promoter of 1 to 0.25 (by volume).

    d. is more economical to use in temperatures below 110°F.

    e. increases pumping/spraying reliability because there are no precipitants similar to the benzoyl peroxide crystals to foul check valves and other pump mechanisms.

RECOMMENDATIONS

1. The search for a Vanadium type promoter component be continued until a satisfactory substitute for Vanadium Ten-Cem is achieved. Upon successful attainment of this objective, the Marine Corps should adopt the new chemical formulation in place of the old formulation for use in constructing expedient flexible membrane surfacings of FRP.

2. Real-time, long-term aging tests should be performed on the new resin in ambient environments of war supply storage locations proposed by the Marine Corps to verify actual shelf life.

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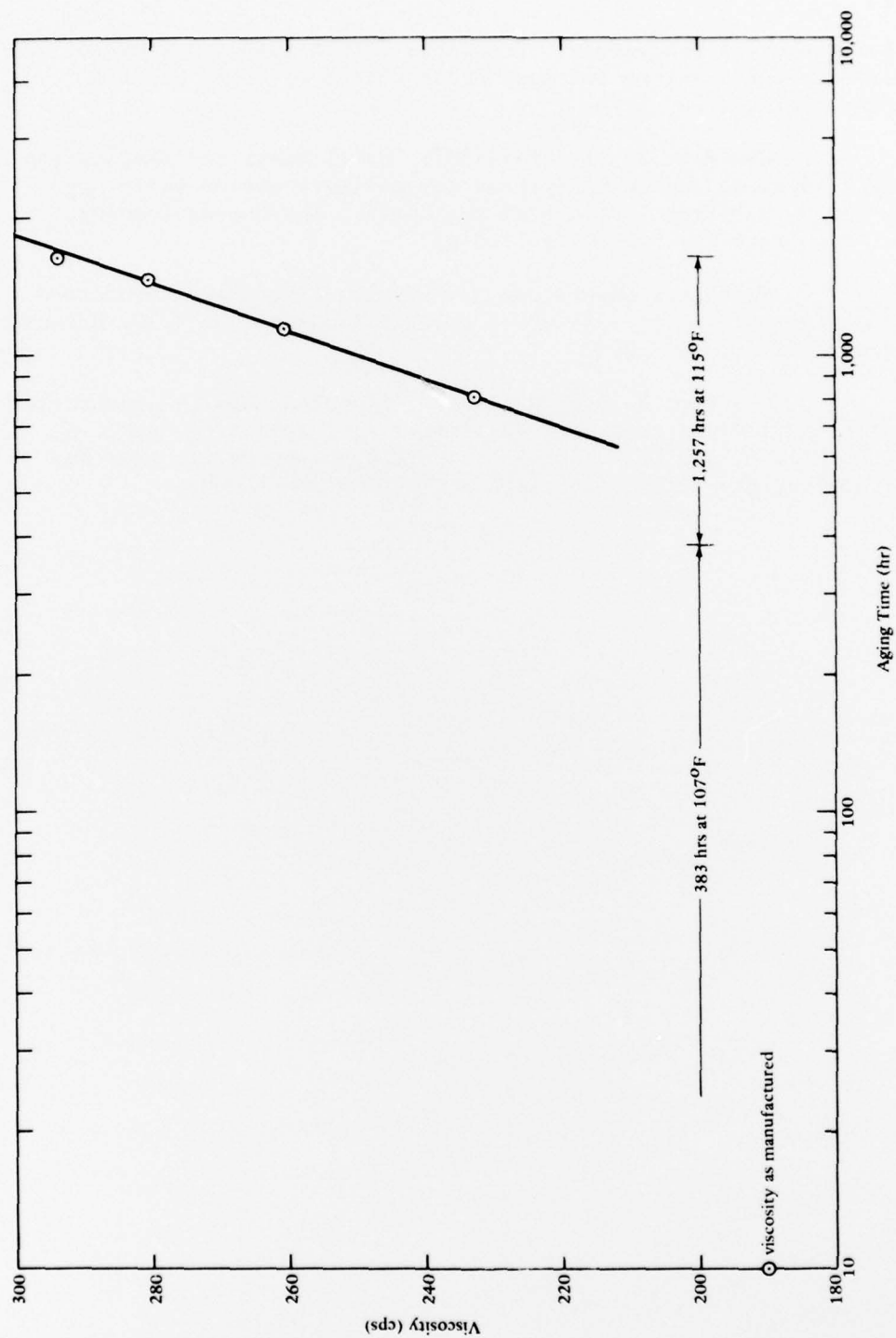
Figure 1. Change in resin viscosity with aging time at 107°F and 115°F. (All viscosity measurements made with a Brookfield Viscometer.)
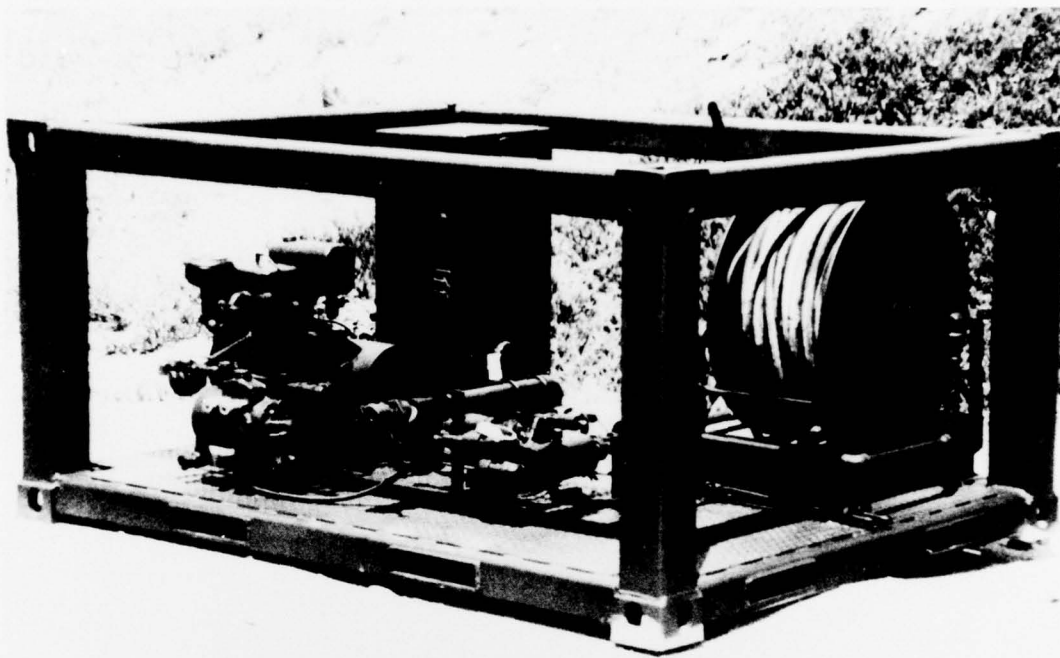
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Figure 2.   SIXCON module for pumping chemical components of FRP surfacings.
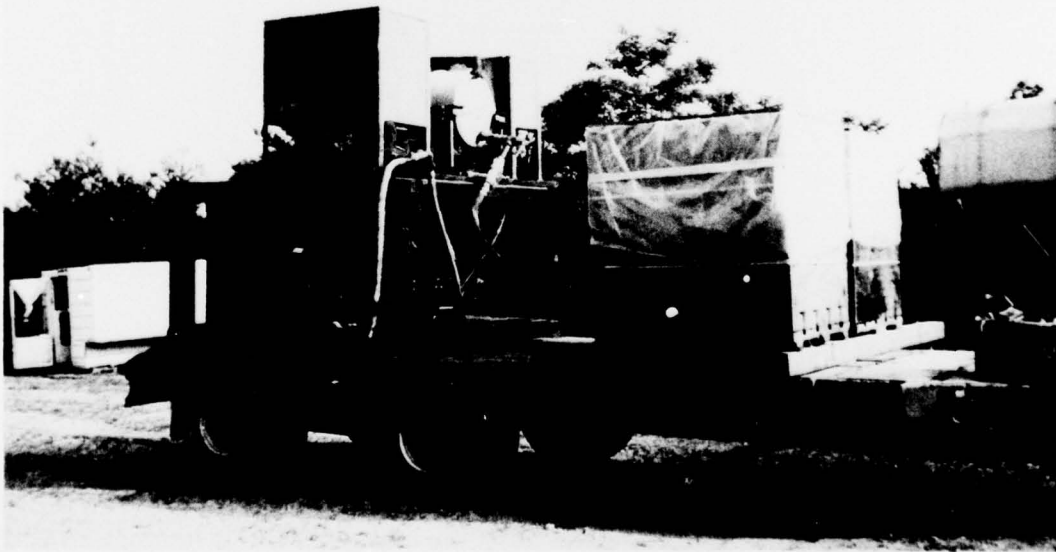

Figure 3.   Spraying equipment setup for field testing of new chemical components.
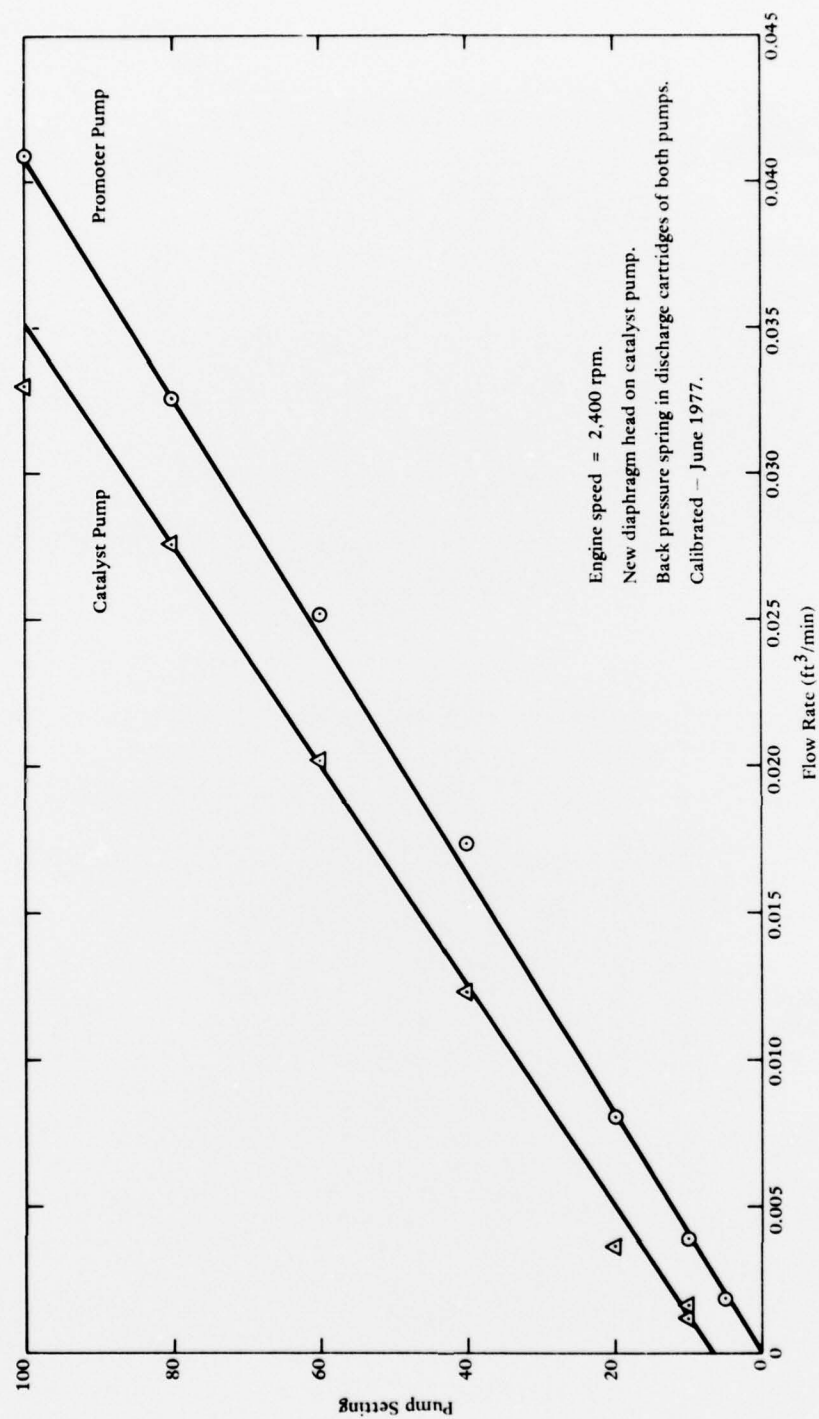
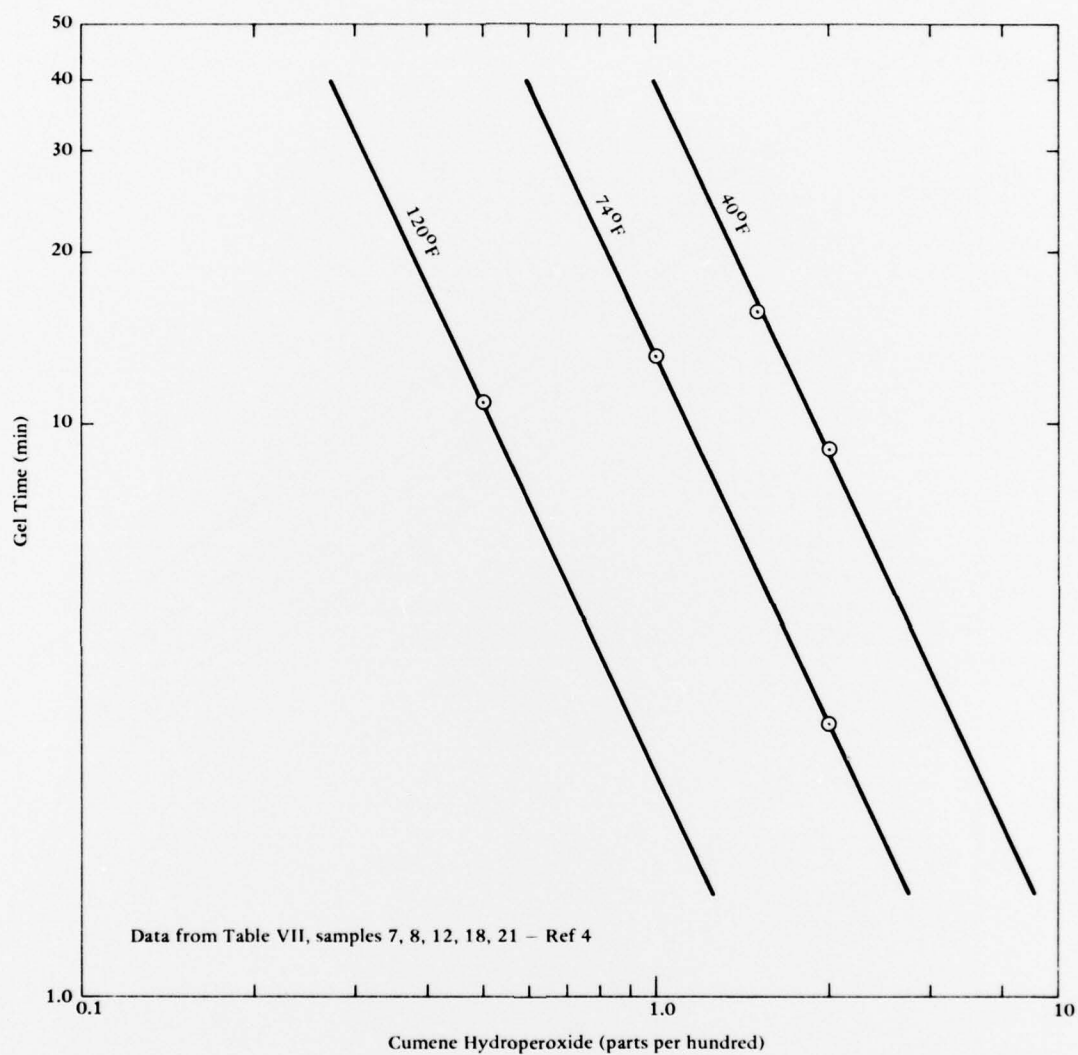Figure 4. Calibration curves for SIXCON catalyst and promoter pumps.

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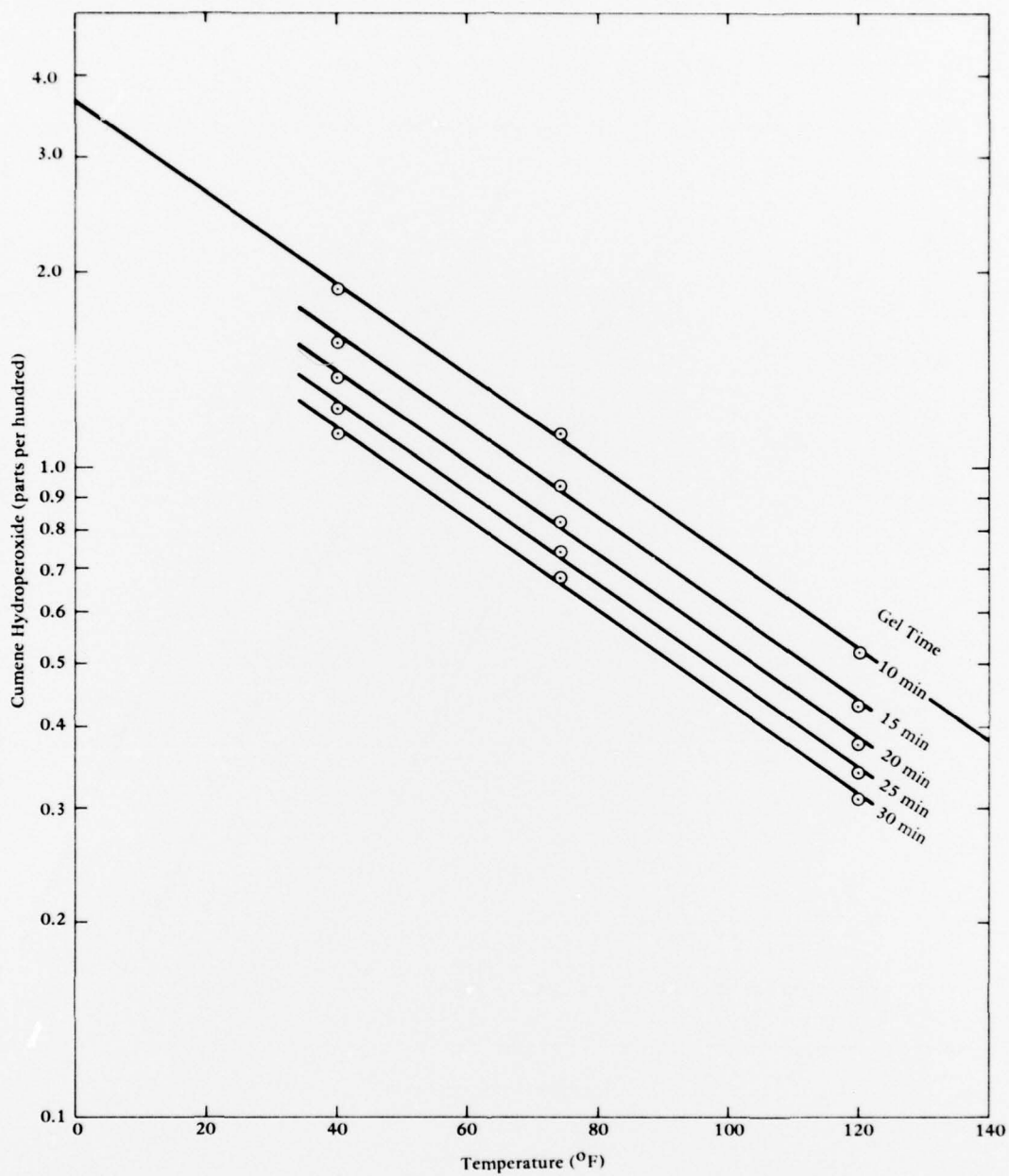Figure 5. Gel time versus cumene hydroperoxide amount required at various temperatures.

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Figure 6. Cumene hydroperoxide required at various temperatures to obtain gel times indicated.
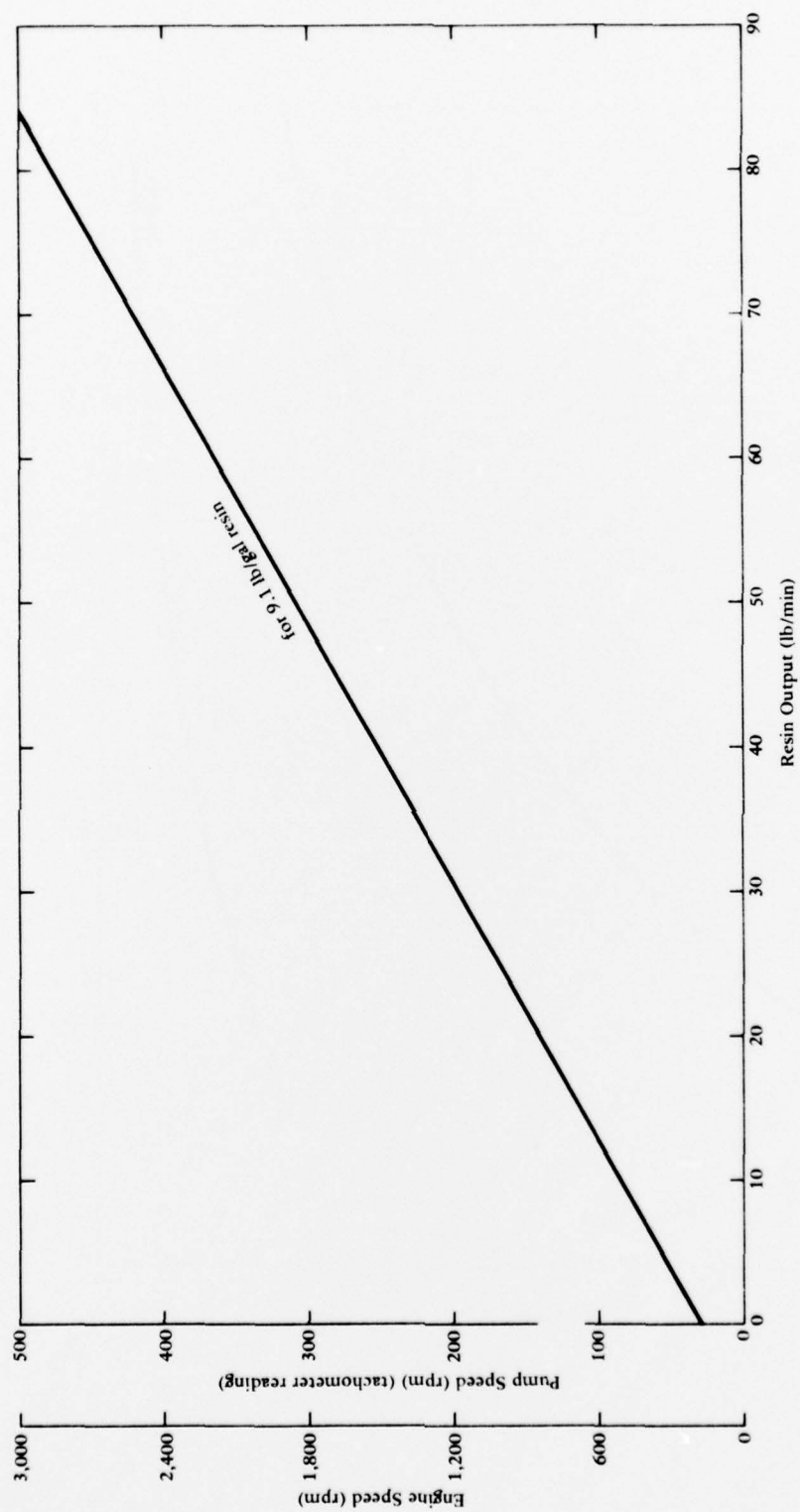
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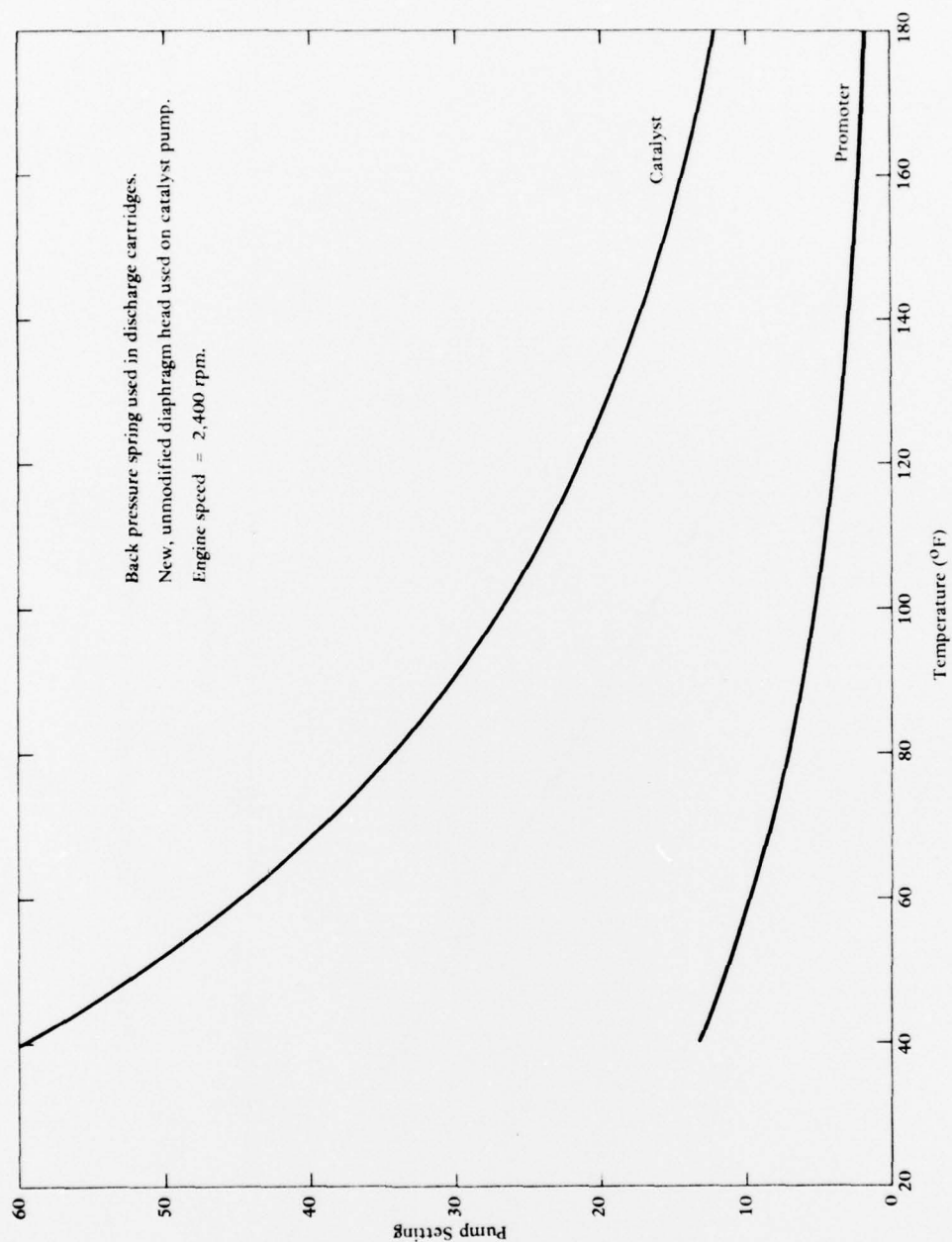Figure 7. Pump output of resin at various pump speeds.

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Figure 8. Pump settings for various temperatures and 10-minute gel time for the SIXCON spraying unit.

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Figure 9.   Removal of rocks and other objects in preparation for FRP
           construction.

Figure 10.   Resin spraying and fiberglass rolling operations.

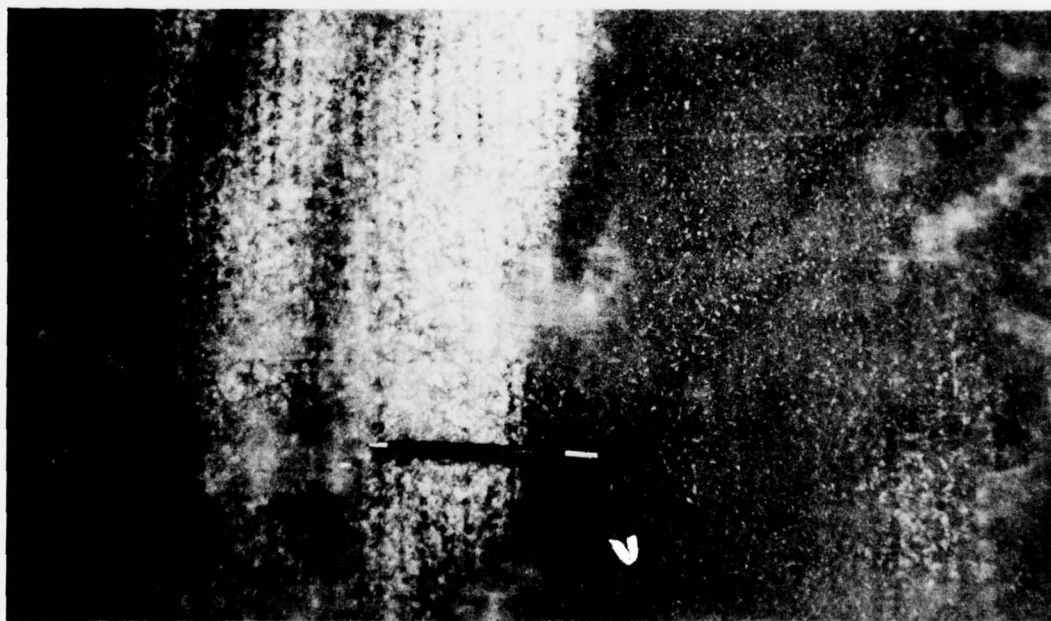Figure 11.   Overall view of completed test pad.

Figure 12.   Resin-starved area.

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Figure 13.   Area with excess resin.

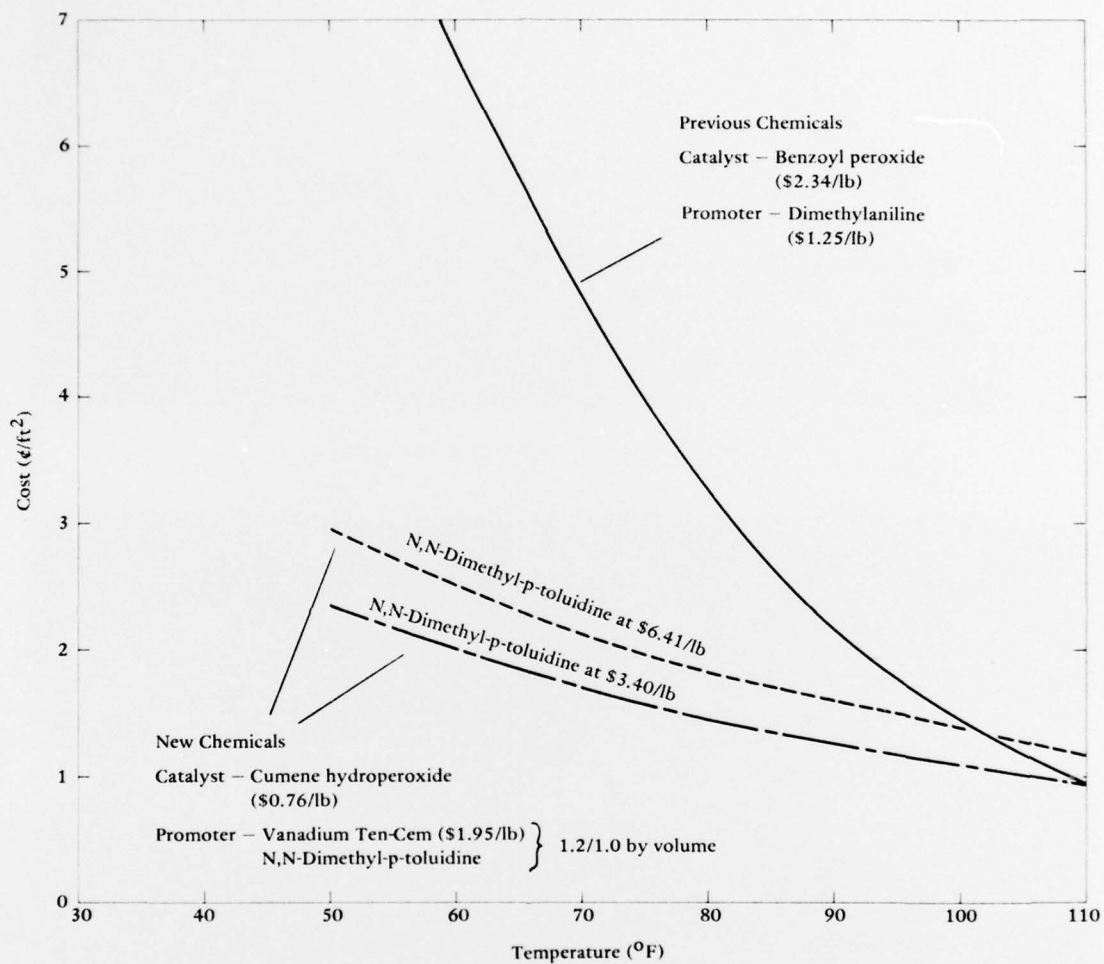Figure 14.   Area with wrinkled fiberglass matting.

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Figure 15. Combined cost of catalyst and promoter to fabricate FRP
surfacings at various temperatures, 10-minute gel time,
and resin application rate of 66.3 lb/min.

Table 1. Composition and Properties of New FRP Chemical Components

Chemical Component	Composition	Shelf Life	Specific Gravity	Viscosity (cps)	Freezing Point (°F)	Boiling Point (°F)	Flash Point (°F)
Polyester resin	(55% polyester resin; 45% styrene and related monomers)	5 yr	1.093	190-210 at 77°F	none	295	90
Cumene hydroperoxide	technical grade	6 mo*	1.026	8.5 at 77°F	16	307	170
Vanadium Ten-Cem (4%)	(98% vanadium neodecanoate; 2% xylene)	developmental item; long shelf life expected	1.043	100 or less (room temp)	not available	279	80
N,N-dimethyl-p-toluidine	technical grade	unlimited	0.935	not available	-81	419	>392

*Manufacturers of cumene hydroperoxide do not recommend long-term storage. If stored at recommended room temperature, the shelf life is stated to be 6 months.

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Table 2. Procurement Information For Chemical Components

Chemical Component	Manufacturer	Manufacturer's Identification	Chemical Grade	1977 Cost* ($/lb)
Polyester resin	PPG Industries, Inc.	RS50338	-	0.68
Cumene hydroperoxide	McKesson Chemicals, Co.	-	technical	0.75
Vanadium Ten-Cem**	Mooney Chemicals, Inc.	973	4% metal content	1.95
N,N-dimethyl-p-toluidine	Mobay Chemical Co.	-	technical	3.40

*Cost is for small quantity orders.
**Vanadium Ten-Cem is no longer available from Mooney Chemicals, Inc. Investigations are being performed to identify an alternate chemical component.

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Table 3. Strength Properties of FRP Specimens Constructed With The New And Old Chemical Formulations

Chemical Type	Resin Age (mo)	Soil Type	Shear Strength* (psi)			Tensile Strength* (psi)			Flexure Strength* (psi)		
			Average	σ	n	Average	σ	n	Average	σ	n
New	accelerated to 30	uniformly graded sand	9,084	2,561	5	10,410**	2,517	6	34,746	5,623	5
New	4	uniformly graded sand	11,890	1,468	5	3,703**	882	5	11,396	6,420	5
Old	5	uniform size sand	7,469	796	5	9,923	1,509	4	12,819	6,497	6
Old	5	lean clay	9,687	1,650	5	7,489	679	4	16,755	5,390	6
Old	5	heavy clay	8,990	1,130	5	6,126	1,058	3	20,688	4,622	6

*σ = standard deviation, n = number of observations.
**These samples all failed at the grips; therefore, actual strengths are higher than those shown.